FONDAZIONE ENI ENRICO MATTEI

NOTA DI LAVORO

77.2016

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Mitigation, Innovation and Transformation Pathways
Series Editor: Massimo Tavoni

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Summary

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Keywords: Clean Power Plan, Climate Change Mitigation Policy, Investment, Electricity, United States

JEL Classification: Q42, Q43, Q48, Q58

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An economic assessment of low-carbon investment flows in the U.S. power sector

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December 6, 2016

Abstract:

This study used the GT NEMS model to analyze how the proposed federal regulation on carbon emissions will impact investments in the U.S. electricity generating capacity at the federal and Census Division level for 2016-2030. Results show that in order to reduce emissions by 32% by 2030, cumulative investments will increase from 399 to 414 billion USD by 2030. Under the scenario which addresses carbon leakage - covering new and existing power plants - cumulative investment will reach 475 billion USD by 2030. Addressing carbon leakage will affect not only the size of the investments but also the direction: when only existing power plants are covered investments in natural gas remains almost unchanged (123 billion USD) relative to the Reference case; while under the scenario that covers all power plants, investment in natural gas will be 24% lower and the investments in renewable will be 64% higher than the Reference. Carbon regulation will produce not only losers and winners among energy sources but also among U.S. states. While the South and Midwest states will experience much higher increase in cumulative investments with respect to the national average; Northeast and West states will reduce their overall investments by 2030 under the policy scenarios.

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Highlights:

- The study analyzed how the proposed federal regulation on carbon emissions will impact investments in the U.S. electricity generating capacity at the federal and Census Division level for 2016-2030.
- The magnitude of investments does not change significantly when the climate policy is introduced but investments in fossil fuels decline by 30% relative to the reference case.
- When carbon leakage is addressed cumulative investment are 20% bigger than in the reference scenario by 2030. Covering existing and new units will require additional 62 billion USD cumulative investment for 2016-2030 with respect to the scenario that covers only existing units.
- Under more aggressive energy efficiency assumptions, total cumulative investments in the power sector decrease by 24-29% in 2016-2030 depending on the policy scenarios.
- At the regional level: South and Midwest states will experience much higher increase in cumulative investments with respect to the national average; Northeast and West states will reduce their overall investments by 2030 under the policy scenarios.

1. Introduction

In 2014, the Environmental Protection Agency of the United States proposed the first federal regulation on CO2 emissions for the power plants, the Clean Power Plan (CPP), finalized in 2015. The CPP set an overall emission reduction target of 32% by 2030 with respect to 2005 and provides state-specific carbon emission standards that each state can meet through a combination of measures that reflect its particular circumstances and policy objectives (EIA, 2015a). In addition, in 2015, the U.S. reinforced its climate mitigation commitment submitting to the UNFCCC its Intended Nationally Determined Contributions (INDCs) with an overall reduction target of 26-28% by 2025 relative to 2005 (UNFCCC, 2016).

Both the direct regulation of power plants under the federal policy and the international pledge under the UNFCCC are very likely to drive a significant change in the way the U.S. produces electricity. The United States has already reduced CO2 emissions from the power sector by 21% in 2015 relative to 2005 in response to environmental regulations, declining consumer demand, increasing supply of natural gas and the retirement of some of the oldest, least efficient and most carbon-intensive power plants (EIA, 2015b). However, the future baseline emissions are too high to be consistent with the national and international U.S. commitments (EPA, 2015a). In particular, several studies have shown how the CPP will influence the future electricity mix and technological transformation at both national and regional level with significant reduction in coal demand and a strong increase in the role played by renewable (Brown et al., 2016, Cullenward et al., 2016, Godby and Coupal, 2016a, 2016b, Ross et al., 2015, 2016, and Lu et al., 2016).

In order to meet federal and international commitments, investments in the power sector will be redirected towards less-emitting energy sources (Wright and Kanudia, 2016 and Wei et al., 2014). Estimating the direction, the size, and the timing of future investment flows is extremely important for policy makers and the business community when negotiating their positions on future climate mitigation strategies at the domestic and international level (Iyer et al., 2015 and Massetti, 2015). The research community is also paying more attention to this topic, and, for the first time, the Fifth Assessment Report of the IPCC Working Group III has dedicated a whole chapter on cross-cutting Investment and financial aspects of climate change mitigation policies (Gupta et al., 2014). However, the assessment of investment flows in the entire power sector under climate mitigation scenarios is still in its infancy. Specifically, only few studies have analyzed the future evolution of electricity supply investments under climate mitigation policies on a global scale (Carraro et al., 2014 and Chaturvedi, 2014) and on a regional scale (Kober et al., 2016) using hypothetical climate mitigation scenarios using integrated assessment models. There are also a growing number of studies that look at the current global climate finance landscape (Buchner et al. 2014). However, the effects of a real climate mitigation policy (like the Clean Power Plan) on electricity supply investments have not yet been investigated.

This study used the GT version of the 2015 National Energy Modeling System (NEMS) (EIA, 2014) to analyze how the proposed federal regulation on carbon emissions will impact investments in the U.S. electricity generating capacity at the federal and Census Division level for 2016-2030. What is the future of conventional fossil fuel plants under the climate policy scenario? How much investment will be directed to the renewable energy? How the investments patterns are going to change when the policy addresses carbon leakage? What will be the effects of increasing energy efficiency on the investment patterns? This paper makes several important contributions. First, it reveals the optimal mix of investments in the U.S. power sector under different policy scenarios. Second, it estimates the distribution of investments across Census Divisions and over time. Finally, it assesses how regulating all power plants to reduce carbon leakage will affect investment flows and composition.

The paper is organized as follows. Section 2 describes the method and policy scenarios used for the analysis. Section 3 discusses the changes in total investment in the power sector in the policy scenarios with respect to the baseline and the new investment mix at the national level. A sensitivity analysis will then test how energy efficiency improvements will affect national investments. The second part of the Result section focuses on investment flows by technology in the nine Census Divisions. Section 4 summarizes the results and discusses the policy implications.

2. Methodology

2.1 The GT-NEMS Model

The National Energy Modeling System (NEMS) is a large-scale mathematical model that computes equilibrium fuel prices based on microeconomic theory and quantities in the U.S. energy sector. It is a technology-rich, energy-economy model of the United States through 2040, which forecasts the production, conversion, consumption, and prices of energy products in future time periods subject to fundamental assumptions on demographic factors, macroeconomic and financial factors, existing policies and legislation, behavioral and technological choice criteria, cost and performance characteristics of all energy technologies, and resource availability and costs. NEMS is also used for preparing forecasts of future energy markets and analyzing the impacts on those markets of government policies and other important influences or developments (EIA, 2014).

For this study, we used the GT-NEMS which is based on the version of NEMS that generated the Annual Energy Outlook 2015 (EIA, 2015a). GT-NEMS is a computational general equilibrium model based on microeconomic theory. Linear programming algorithms and other optimization techniques provide the foundation with which GT-NEMS develops forecasts of the U.S. energy future. With twelve modules, plus a thirteenth integrating module, GT-NEMS performs an iterative optimization process that results in the price and quantity that balance the demand and supply in the U.S. energy market.

2.2 Assumptions

This paper focuses on investments in electricity supply that need to meet electricity demand in the U.S. under the Reference scenario (no CPP) and Climate Policy scenarios (CPP). In this paper investments refer to expenditures to increase power capacity. When estimating investments, we include the risks associated with a particular technology assigning higher cost of capital investments, the average lifetime of different power plants and the degradation rate (Table 1). First, we take into account the investment risks across U.S. states based on different initial investment costs. Then, to reveal the declining performance of each technology in practice, solar and wind are assigned with a degradation rate of 1% (Jordan and Kurtz, 2013) and 1.6% respectively (Staffell and Green, 2014) while other technologies are assumed to be zero (Tidball et al., 2010). NEMS includes a learning-by-doing via experience curves that decrease investment costs of power plants with accumulated installed capacity (EIA, 2014). Finally, the results are presented by discounting the annual investment flow into the net present value using a 3% discount rate.

2.3 Scenarios

In this study, we used EIA's Annual Energy Outlook 2015 as a Reference scenario. In this scenario, all the current policies are retained. This Reference case is then modified in steps to update assumptions about various resource costs, technology performance, and current policies (EIA, 2015b).

In the CPP scenarios, we assume a mass-based target of 32 % by 2030 relative to 2005. The proposed CPP does address only emissions reduction for existing power plants. However, several critiques of this approach have emphasized the high risk of carbon leakage which occurs when an environmental policy causes an increase of pollution outside its scope, a phenomenon that effectively reduces its environmental benefits (Reference). Under the CPP, there is the possibility of leakage of carbon emissions from affected units to new sources that would not be covered. In order to take this issue into consideration, we analyzed both the CPP applied to only existing (CPP_Existing) and the CPP applied to all electric generating units (EGUs) (CPP_All). All scenarios are described in Table 2. In addition to the CPP, the climate policy scenarios included the Clean Energy Incentive Program (CEIP) which provides additional incentives for wind and solar energy resources.

Table 1.

Initial Capital Cost of Electricity Generating Technology.

Technology	Initial investment cost (2013$/kW)	Lifetime (years)
Pulverized coal	2,910	30-60
Pulverized coal with CCS	6,387	30-60
Coal integrated gasification combined cycle	3,677	30-60
Natural gas conventional combined cycle	669	30-45
Natural gas advanced combined cycle	1,007	30-45
Natural gas conventional combustion turbine	967	30-45
Natural gas advanced combustion turbine	669	30-45
Natural gas with CCS	2,040	30-45
Nuclear	4,660	60
Hydropower	3,288	50-100
Wind (onshore)	1,961	20-30
Wind (offshore)	6,080	20
Solar (PV)	3,113	30
Solar thermal	3,638	30
Biomass	3,599	30-45
Geothermal	2,424	20-30
Waste	8,263	15-20

Sources: EIA (2013); Tidball et al. (2010).

Table 2.

Scenario Description.

Scenario	Description
Reference	Annual Energy Outlook 2015 Reference Case.
CPP_Existing	CPP state-level goals for CO_2 mass emissions from existing electric generating units affected by the regulation. Constraints at the state level are aggregated into the 22 NERC region constraints using weights based on a matrix of state-to-NERC-region generation in 2012.
CPP_All	CPP state-level goals for CO_2 mass emissions from existing and new electric generating units affected by the regulation. Constraints at the state level are aggregated into 22 NERC region constraints using weights based on a matrix of state-to-NERC-region generation in 2012.

3. Results

3.1 National investments in electricity sector

In this section, we discussed national investments in the power sector under the Reference scenario and the two climate policy scenarios (CPP_Existing and CPP_All).

In the Reference scenario the mean estimate of the annual investments in the power sector is 28 billion USD for 2016-2030. Under the climate policy scenarios, average annual investments increase to 29 billion USD (CPP_Existing) and 34 billion USD (CPP_All). In particular, after 2019 both policy scenarios experienced an increase in annual investment flow to meet the emission reduction target and they peak around 2020-2021. After that, they return close to the baseline level. Comparing the two CPP scenarios, the one that covers both existing and new power plants (CPP_All) will require higher investments that the one on only existing EGUs (CPP_Existing) because the implementation of emission standards to the new EGUs tends to accelerate the shift to cleaner electricity sources which require higher investment per capacity installed (Fig. 1).

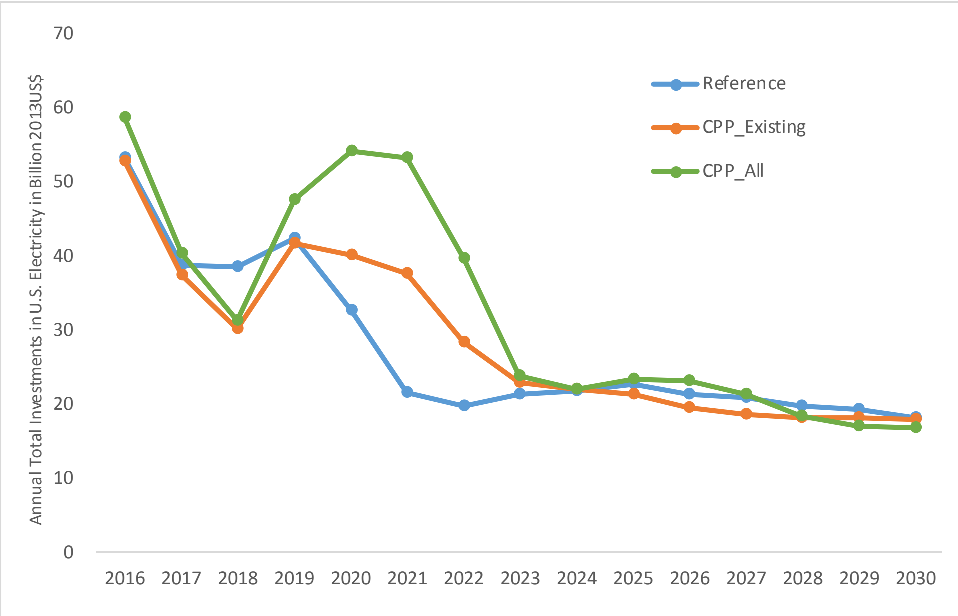

Fig. 1.

Annual investments in additional power capacity under different scenarios (present value in billion 2013$ from 2016 to 2030).

Fig. 2 shows cumulative investments towards different technologies under different scenarios. Cumulatively under the Reference scenario, 399 billion USD is expected to be invested in additional power supply. Without a climate policy target, 32% of them is expected to go to fossil fuel generation, in particular natural gas. The mean estimate of annual investments in fossil fuels is equal to 9.2 billion USD for 2016-2030. The picture does not change significantly when the climate policy is introduced: under the CPP_Existing scenario, total capital investments increased by 3%, with an average annual investment in fossil fuels of 8.9 billion USD and a declining share of 30% on total investments. On the other hand, addressing carbon leakage sustainably affects these results. Under the CPP_All scenario cumulative investments are equal to 475 billion USD, which is approximately 20% more than the Reference scenario. Under this scenario cumulative investments in fossil fuels decline by 24% while cumulative investments in renewable increases by 64% by 2030.

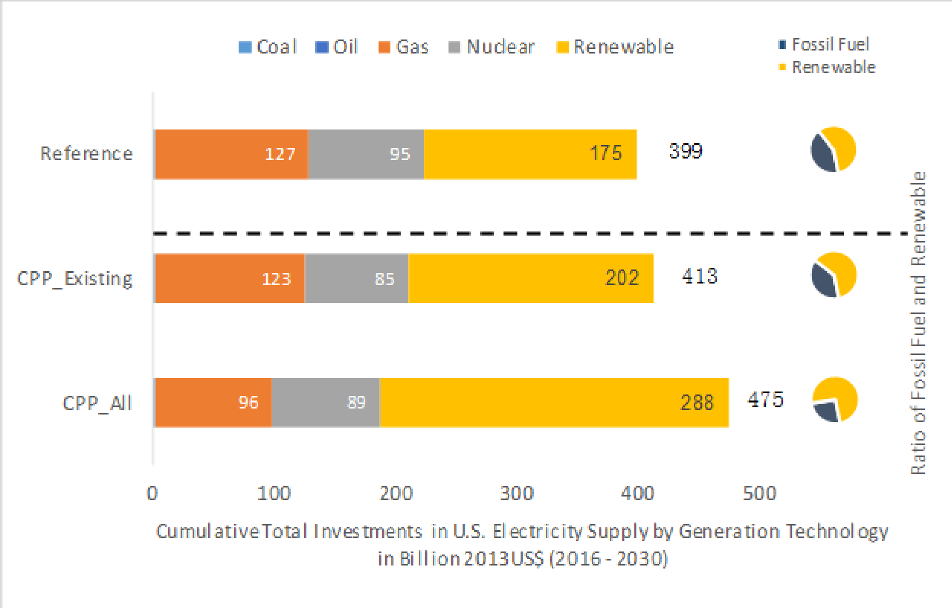

Fig. 2.

Cumulative investments in additional power capacity by energy sources under different scenarios (present value in billion 2013$ from 2016 to 2030).

In all scenarios, additional investments in coal power capacity will cease immediately. Under the Reference scenario, significant coal retirements are expected in the near term due to an increasing competition with low-priced natural gas and the implementation of environmental regulations (Table 3). In addition, the introduction of the climate policy will accelerate the transition from coal to a cleaner fossil fuel – natural gas – and renewables. Finally, in compliance with the EPA's Mercury and Air Toxics Standards (MATS), an additional portion of retirements will occur between 2020 and 2025 in all scenarios.

Cleaner alternatives to use coal have already been implemented or under development. For example, the Integrated Gasification Combined Cycle (IGCC) has been used in several operating power plants and there are few pilot projects with the carbon capture and storage (CCS) technology applied to coal power plants (Markewitz et al. 2012). However, both technological options will require high upfront capital costs and expenditures on fuels making them less competitive with respect to less carbon-intensive technologies like natural gas. Our results show indeed minimal investments directed towards clean coal.

Table 3.

Cumulative retirements of coal capacity by 2030 (GW).

	2015	2016	2020	2025	2030
Reference	14	38	45	48	48
CPP_Existing	14	42	49	73	73
CPP_All	14	45	50	75	80

Natural gas is not projected to play a marginal role as coal. As a cheap and available resource in U.S. and less carbon-intensive than conventional coal, it is expected to be a major baseload energy source in all scenarios. Investments in gas power plants will not diverge significantly across scenarios with an annual average investment of 9 billion USD for the Reference and the CPP_Existing scenarios and 7 billion USD for CPP_All. Most interestingly, the CPP_Existing will require higher investments in additional natural gas capacity than the other two scenarios. This will happen because of a strong incentive in investing in new NGCC units (not covered by the CPP) which are less carbon-intensive than coal and the most cost-effective complement for nuclear and renewable energy. In addition, under the CPP_Existing investors will be willing to use more natural gas to replace the coal capacity (Brown et al., 2016, Ross and Murray, 2016 and EIA, 2015a). On the other hand, under the CPP_All, the coverage of all units (new and existing) in order to address carbon leakage will affect negatively the flow if investments towards additional gas capacity (Fig. 3a).

Among natural gas the biggest portion of investments is directed toward Combined Cycle (CC) and Combustion Turbine (CT). Under the CPP_Existing scenario, natural gas-fired CC will attract 67-82% of total investments in gas power generation from 2016 to 2030; while investments in CTs will fall to 20% by 2030. The CC option attracts more investments because it produces electricity more efficiently operating similarly to combustion turbine, but also re-using waste heat.

Table 4.

Percentage of combined cycle and combustion turbine in the total natural gas investments under different scenarios.

%	2016	2020	2025	2030
Combined Cycle (CC)				
Reference	71%	33%	61%	50%
CPP_Existing	67%	69%	82%	72%
CPP_All	67%	62%	62%	51%
Combustion Turbine (CT)				
Reference	22%	48%	33%	43%
CPP_Existing	24%	29%	18%	21%
CPP_All	24%	37%	31%	42%

Nuclear is a cleaner energy source option. However, the large adoption of nuclear has been long controversial because of a security concern and a higher cost (EIA, 2015a, 2015b). In particular, our results show that investments in additional capacity for nuclear power plants remain almost unchanged across scenarios with an annual average investment of 6.8 billion USD for the Reference, 6.1 billion USD for CPP_Existing and 6.3 billion USD for CPP_All (Fig. 3b). Additional nuclear capacity is mainly due to the new reactors (including the five under construction in the U.S.) and expansions of existing plants that will count toward state compliance with the plan's requirements as new sources of low-carbon energy under the climate policy scenarios.

On the other hand, investments in renewable energy will increase in all scenarios with an annual average investment of 13 billion USD for the Reference, 14 billion USD for CPP_Existing and 21 billion USD for CPP_All (Fig. 3c). In addition, engaging new EGUs with a new emission standard (CPP_All) will be a stronger incentive towards more investment on renewable sources than the regulation on only existing generators (CPP_Existing). This is an indirect effect of reducing the carbon leakage problem: while under the CPP_Existing more investments will be toward cleaner fossil fuel sources under the CPP_All they will be toward renewables. Renewable generation technologies will require higher up front capital investments than fossil fuel power plants, but no direct expenditure on fuels.

Among renewable energy sources, hydropower, solar, and wind are the ones expected to experience the highest increase in their investment flows under climate mitigation policy scenarios thanks to the maturity of the technology and competitive initial investment cost. While hydropower will remain largely unaffected by the climate policy with an annual average investment of 0.4 billion

USD; the CPP will significantly change investments on wind and solar by substantially enhancing their share in the total renewable generation. If in the Reference case the total of wind and solar accounts for an annual average investment of 9.7 billion USD, in the policy scenarios they reach 12 billion USD and 17 billion USD under the CPP_Existing and CPP_All respectively. In particular, the climate policy will empower an urgent investment in solar and wind during the first five years. While wind will dominate investment flows in monetary terms (increasing from average annual investments of 8 billion USD to 10-13 billion USD), solar will experience a faster growth rate under the CPP scenarios. Finally, other renewable energy such as geothermal, biomass will see a slight increase after 2020 under the policy scenarios relative to the Reference scenario.

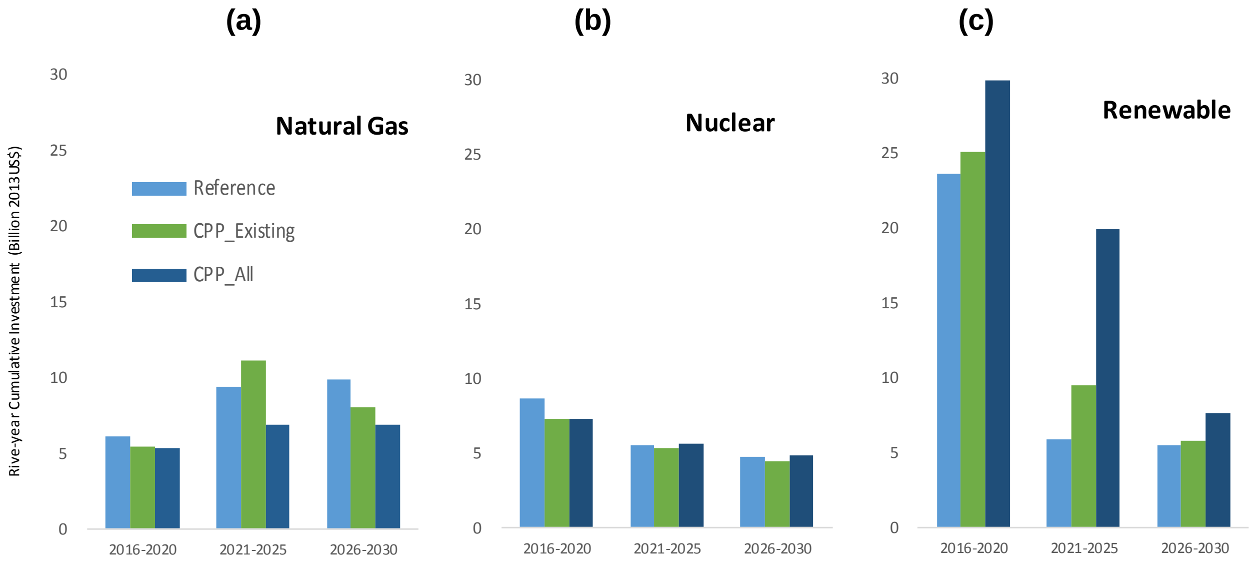

Fig. 3.

Five-year average investments in U.S. electricity by energy sources in the Reference and the CPP basic scenarios (present value in billion 2013$ from 2016 to 2030).

3.1.1 Sensitivity Analysis of National Results

Our results show that climate policy will increase investment needs in the power sector. However, the climate policy will also make power generation more expensive, in this way increasing the incentive to reduce the demand for electricity which will eventually decrease the need for investments. In this section we assess how more energy efficiency improvements will affect the total investments in the power sectors. In order to answer this question, we stimulate two additional policy scenarios (All and Existing) under more aggressive assumptions on energy efficiency in commercial, residential and industrial sectors[1]. By comparing the two CPP scenarios with and without energy efficiency improvements, our results show that under more aggressive energy efficiency assumptions, total cumulative investments in the power sector decrease by 24-29% in 2016-2030 depending on the policy scenarios because of a reduction in electricity production (Brown et al. 2016). Cumulative Investments in renewable will be the ones affected the most with a reduction of 41-45%, while investments in fossil fuels will drop by 7% in the CPP_All scenario and by 13% in the CPP_Existing scenario. The additional energy efficiency improvements

[1] Commercial energy-efficiency enhancements including space heating and cooling equipment with stronger standards for rooftop units beginning in 2018 and in 2023. Energy efficiency is improved in residential building equipment and appliance standards, including room air conditioners, water heaters, a variety of types of lighting, and such many things. Industrial energy efficiency improvements are processed with a 30% investment tax credits for large-scale (49MW+) CHP through 2040 and five manufacturing subsectors (Brown et la., 2016a, 2016b).

accompanied by the inclusion of new NGCC units under the CPP_Existing scenario will increase even more the role of natural gas deployment and delay investments toward renewable energy.

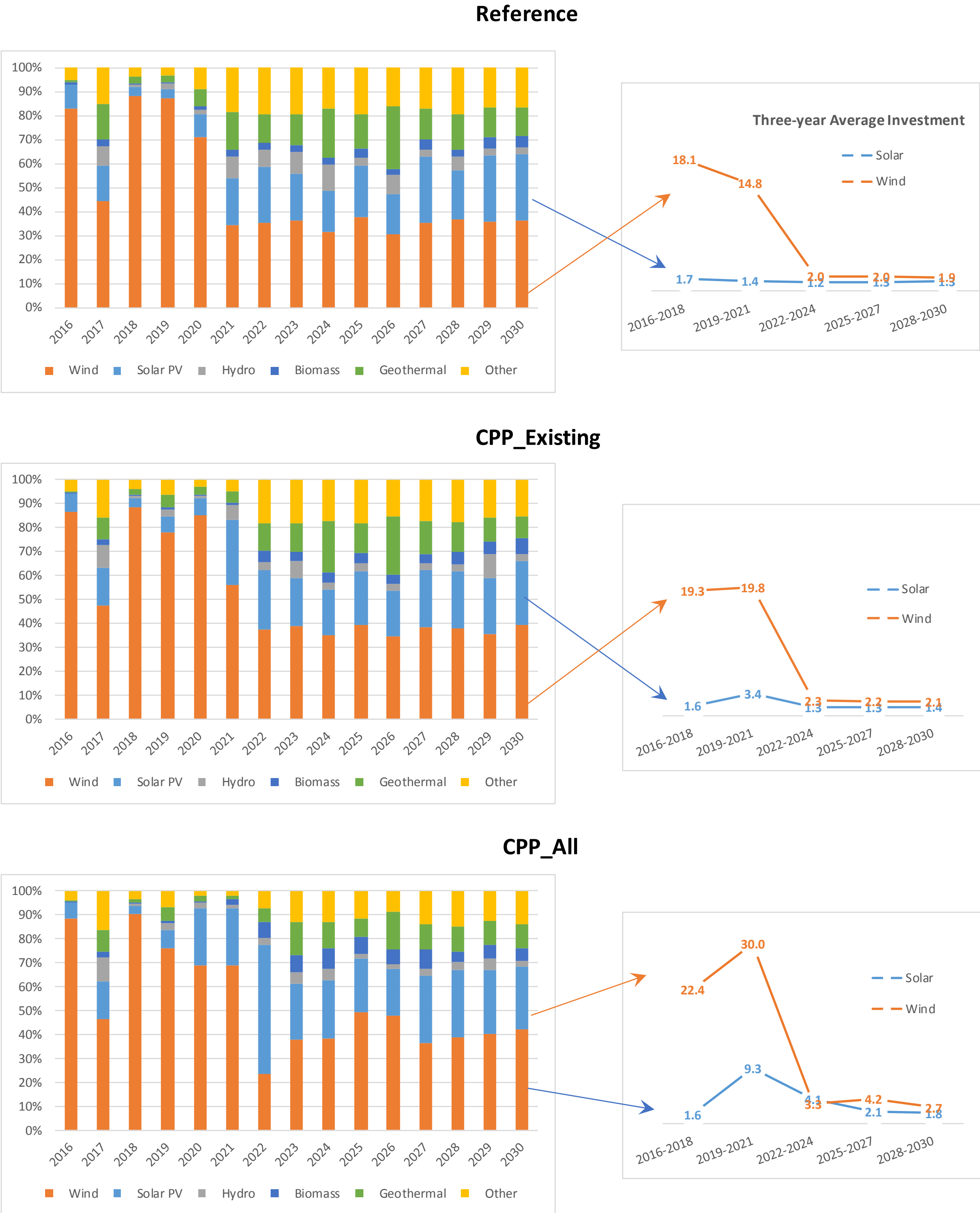

Fig. 4.

Percentage of non-hydro renewable in total renewable investments (left); Three-year average investment flow in solar and wind (present value in billion 2013$, right).

Note: average investments are assessed in three years consistent with the CPP compliance period

3.2 Electricity Investments in Census Divisions

In this section we discuss how regions will respond to the climate regulation estimating investments in the power sector for each Census Division under the Reference and two climate mitigation scenarios. The strong heterogeneity of the current electricity mix among U.S. states makes fundamental to assess their responses to the climate policy target. For instance, the increase in total investments under the CPP is not distributed homogeneously across regions. While some states will experience a much higher increase in cumulative investment with respect to the national average; others will reduce their overall investments by 2030 if the policy is enacted (Fig. 5). Carbon regulation will indeed produce not only losers and winners among energy sources but also among US states.

In the Reference scenario, the South Atlantic area has the highest demand for investments in additional capacity covering 21% of total U.S. investments for 2016-2030. A significant share of these investments will happen between 2020 and 2025 and will be directed mainly to additional capacity in the nuclear power plants.

Under the policy scenarios, the South Atlantic will be again the region with the highest investments in additional capacity ranging from 80 to 110 billion USD and covering 20% and 22% of total U.S. investments for 2016-2030 under the CPP_Existing and CCP_All respectively.

On the one hand, all the South regions together with Midwest regions will experience an increase in the cumulative investments with respect to the Reference case. As in the Reference scenario, the majority of the additional investments, up to 50%, will flow to the fossil fuel generation. However, the climate policy will restructure the power sector of these two macro-regions by enhancing large portion of clean energy and an overall increase in investments on renewable of 55-85% (Fig. 6).

Particularly, under the CPP_Existing, the West North Central division will have the highest increase of investment in percentage terms relative to the Reference. Of the additional 51 billion USD cumulative investments for 2016-2030 80% will be directed toward the wind sector. On the other hand, if new units are regulated (CPP_All), the East North Central will more than double cumulative investments with a total of 91 billion USD in 2016-2030. The 76% of investments in this region will be directed toward additional wind capacity for a total of 69 billion USD. Even if in a much smaller share biomass will continuously attract investment cumulating nearly 0.9 billion USD.

The generation portfolio in the South area spread through a variety of energy sources such as solar, wind, hydropower, and biomass despite the domination of natural gas and nuclear. Unlike the Midwest area, solar and biomass are playing the most important role in the South area under the climate regulation scenarios. Particularly, under the CPP_All scenario, the South Atlantic will add nearly 24 billion USD in additional solar power while the East South Central will invest nearly 2 billion USD in biomass, recording the highest investments in both technologies across the nation.

Another important aspect in the South area is the divergence of investments in the South Atlantic and East South Central under the two CPP scenarios while investments in West South Central are almost unchanged. This is because in the West South Central regions, investments in additional gas will be almost unchanged under all scenarios and there will be only an increase in wind investments under the CPP_All.

On the other hand, in the Northeast and West divisions cumulative investments will be reduced up to 13% under the policy scenarios compared with the Reference case. In particular, even if the Northeast will increase its investments in solar by 30%, the overall investments will be reduced due to a decrease of 25-35% in natural gas and 10% in nuclear under the CPP_Existing and CPP_All scenarios. In the West area, where wind and geothermal power have been highly driven by current policies, the CPP will drive even more investments in solar (6-10 billion USD for 2016-2030). However, the total investments by 2030 of these regions are still slightly declining in both policy scenarios because both fossil fuels and nuclear are rapidly losing its market share with a reduction in investment in additional natural gas capacity of 17-25% and in additional nuclear capacity of 11%, depending on the scenario.

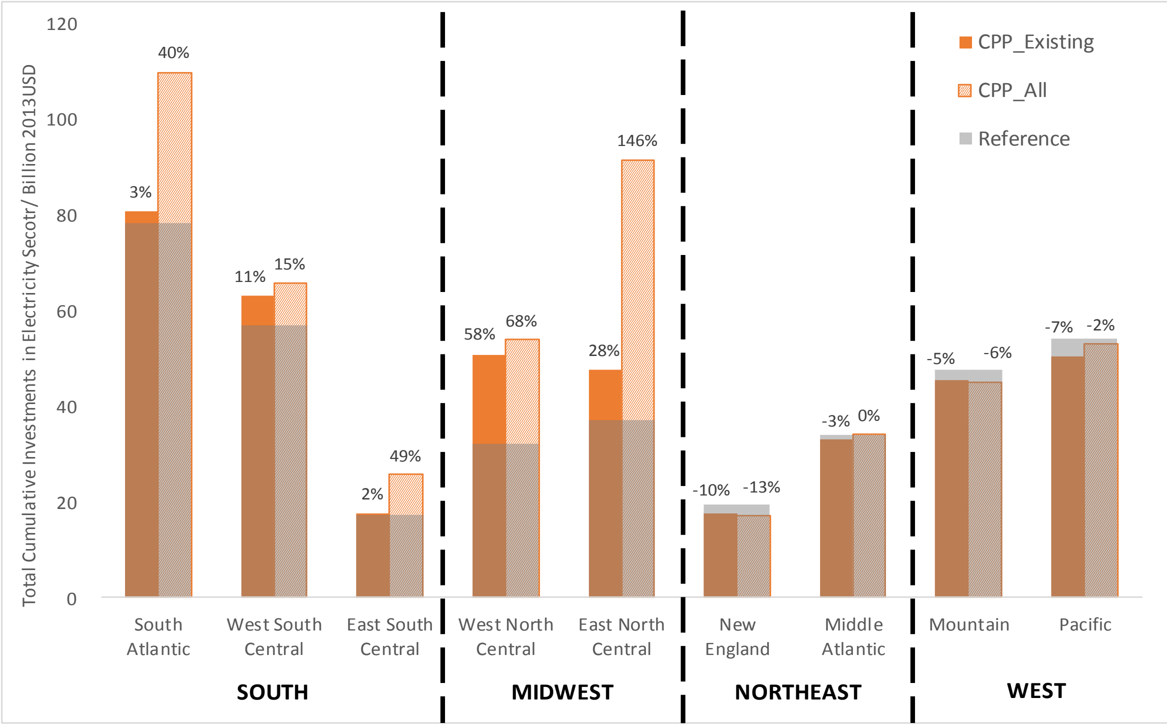

Fig. 5.

Total cumulative investments in electricity by Census Divisions under Reference and CPP scenarios (present value in billion 2013$ from 2016 to 2030).

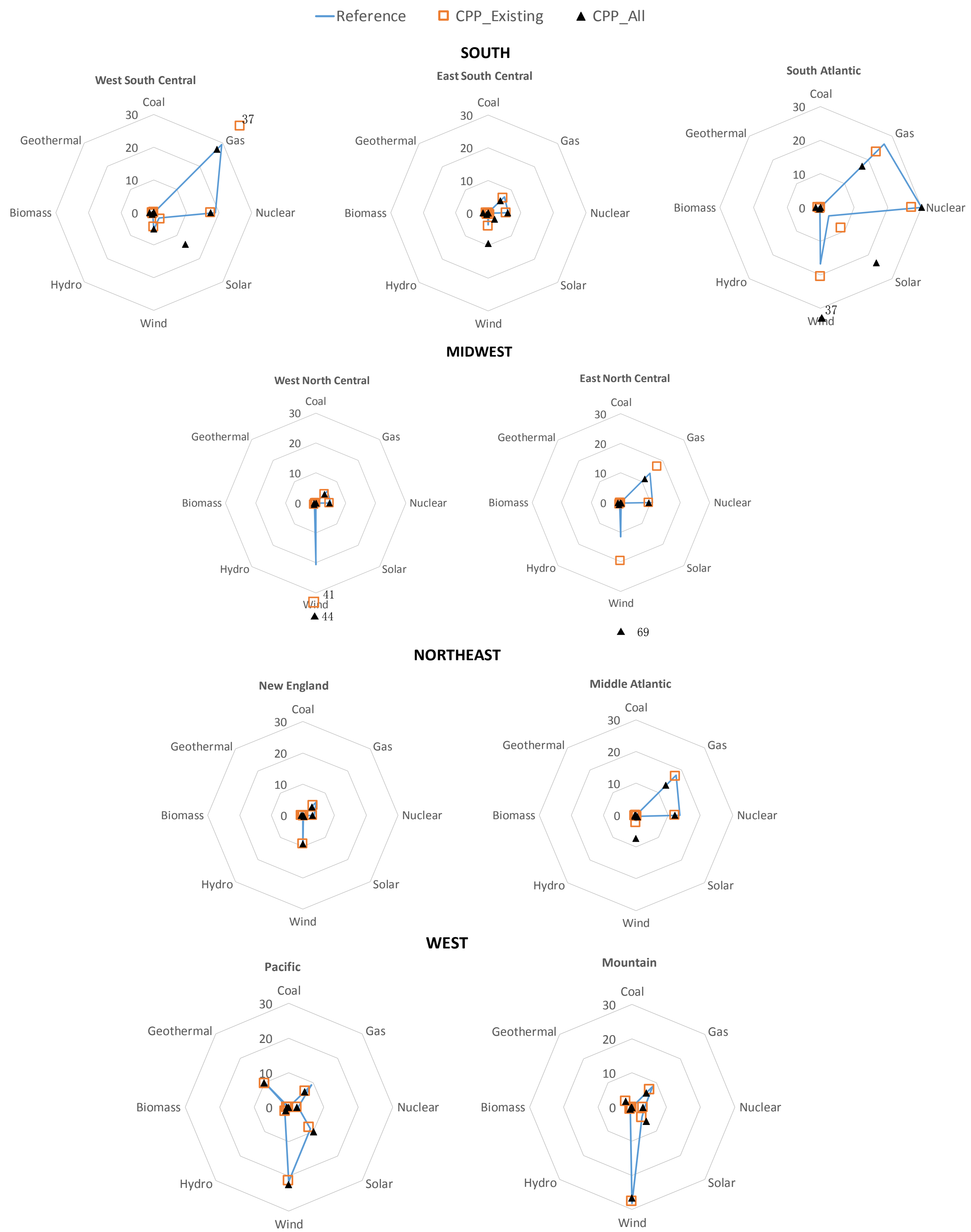

Fig. 6.
Cumulative investments in generating technologies in each Census Division under the Reference and CPP scenarios in billion USD (present value in 2013$ from 2016 to 2030).

Note: numbers larger than 30 are marked outside the range.

4. Conclusions

Estimating the direction, the size, and the timing of future investment flows under different policy scenarios is extremely important for policy makers and the business community when negotiating their positions on future climate mitigation strategies at the domestic and international level. Estimating the direction, the size, and the timing of future investment flows under different policy scenarios is extremely important for policy makers and the business community when negotiating their positions on future climate mitigation strategies at the domestic and international level. However, the assessment of investment flows in the power sector under climate mitigation scenarios is still in its infancy and only few studies have estimated the future evolution of electricity supply investments (under climate mitigation scenarios) at the global or regional scale. In addition, the effects of a real climate mitigation policy (like the Clean Power Plan) on the investments in the electricity supply have not yet been investigated.

This study used the GT NEMS model to analyze how the proposed federal regulation on carbon emissions (CPP scenarios) will impact investments in the U.S. electricity generating capacity at the federal and Census Division level for 2016-2030.

This paper makes several important contributions.

First, it reveals the optimal mix of investments in the U.S. power sector under different policy scenarios. What is the future of conventional fossil fuel plants under the climate policy scenario? How much investment will be directed to the renewable energy? Results show that in order to reduce emissions by 32% by 2030, cumulative investments will increase by 3-24% by 2030. Investments in fossil fuels and nuclear will be reduced by 3-24% and 6-10% respectively, while investments in renewable will increase by 15-64%.

Second, it assesses how regulating all power plants to reduce carbon leakage will affect investment flows and composition. How the investments patterns are going to change when the policy addresses carbon leakage? Results show that addressing carbon leakage will produce two important effects on the investments estimate. First, it will require additional 62 billion USD cumulative investment for 2016-2030 with respect to the scenario that covers only existing units (CPP_Existing). This number can be compared with the estimated cumulative social cost of carbon leakage of 32 billion USD due to an extra emissions of 812 million tons CO_2 for 2016-2030.[2] Second, it will decrease investment toward gas power plants by 22% and increase investment toward renewable by 15% relative to the scenario with only existing power plants covered.

Third, it analyzed the effects of energy efficiency improvements on cumulative investments under climate regulation. What will be the effects of increasing energy efficiency on fossil fuel and renewable investment patterns? Our results show that with under more aggressive energy efficiency assumptions, total cumulative investments in the power sector decreases by 30-34% depending on the policy scenarios the for 2016-2030. In particular, the energy efficiency improvements accompanied by the inclusion of new NGCC units under the CPP_Existing scenario will increase the role of natural gas deployment and delay investments toward renewable energy.

Finally, it estimates the distribution of investments across Census Divisions and over time. Results show that while the South and West states will experience a much higher increase in cumulative investments with respect to the national average; Northeast and West states will reduce their overall investments by 2030 if the policy is enacted.

[2] We use EPA's estimate of the social cost of carbon for 2016-2030 and 3% discount rate.

Acknowledgements

The authors thank Yufei Li at the Georgia Institute of Technology and Yi-Ming Wei at the Center for Energy and Environmental Policy Research, Beijing Institute of Technology for comments that greatly improved the manuscript. Any remaining errors are solely the responsibility of the authors.

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